NONDESTRUCTIVE ANALYSIS OF APOLLO SAMPLES BY MICRO-CT AND MICRO-XRF ANALYSIS: A PET STYLE EXAMINATION.

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Introduction: An integral part of any sample return mission is the initial description and classification of returned samples by the preliminary examination team (PET). The goal of a PET is to characterize and classify the returned samples, making this information available to the general research community who can then conduct more in-depth studies on the samples. A PET strives to minimize the impact their work has on the sample suite, which often limits the PET work to largely visual measurements and observations like optical microscopy. More modern techniques can also be utilized by future PET to nondestructively characterize astromaterials in a more rigorous way. Here we present our recent analyses of Apollo samples 14321 and 14305 by micro-CT and micro-XRF (respectively), assess the potential for discovery of "new" Apollo samples for scientific study, and evaluate the usefulness of these techniques in future PET efforts.

Fig 1: (top) Sample 14305,483 used for micro-XRF analysis. Sample is wrapped in Al-foil and is 8 cm across. **(bottom)** Sample 14321,1404 used in the micro-CT measurement triply bagged in Teflon (right) and inside of the cardboard tube used to immobilize the sample for analysis (inset). Sample is 10 cm across.

Fig. 2: Slices of the micro-CT scan of sample 14321,1404. Brightness is proportional to density. Thus, the very bright phase in the bottom image Is likely a chunk of FeNi metal, and the dark clast in the top image is likely plagioclase rich.

Methods: An x-ray computed tomography (micro-CT) measurement involves scanning samples with high-energy x-rays and constructing 3-dimensional images of the density of materials within the sample. It has the sensitivity to distinguish the major rock forming minerals and identify distinct clast populations within brecciated samples. A scan was made in the Engineering Directorate at Johnson Space Center of sample 14321,1404, a 346.9 g (10 x 9 x 4 cm) chunk of an

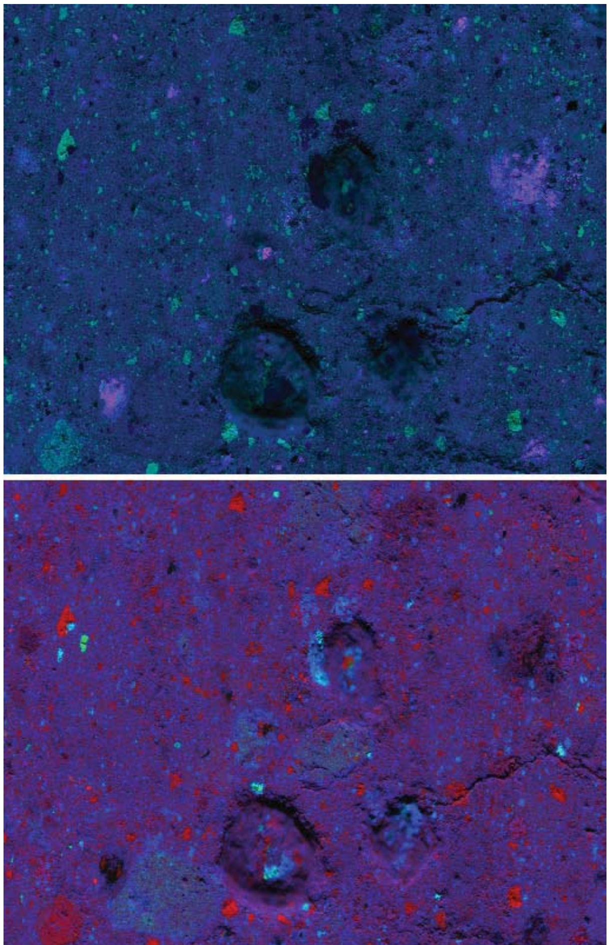

Fig. 3: RGB composite images of micro-XRF derived x-ray maps of 14305,483. **(top)** – red = Ca, green = Mg, blue = Fe. **(bottom)** – red = K, green = Al, blue = Si. Field of view is 6.5 cm wide.

Apollo 14 breccia. The sample was scanned triply bagged in Teflon to preserve the pristine nature of the sample, and inside of a cardboard tube to prevent movement during the analysis (Fig. 1). The measurement was made at an accelerating voltage of 145 kV, a beam current of 140 μA, and an effective voxel size of 45 microns.

Bench top micro x-ray fluorescence (micro-XRF) instruments can rapidly scan large areas (~100 cm^2) with a small pixel size (~25 um) and measure the semi-quantitative composition of largely unprepared surfaces for all elements between Be and U, often with sensitivity on the order of a ~100 ppm. Micro-XRF scans were made on sample 14305,483 in the EDAX Orbis PC micro-XRF at Washington University in St. louis. 14305,483 is a 156 g (8 x 5 x 1.5 cm) slab of an Apollo 14 breccia (Fig. 1). The sample was scanned without a protective bag using an accelerating voltage of 45 kV, a beam current of 800 μA, a beam diameter of 30 μm, and a beam spacing of 30-120 μm.

Results: The micro-CT scan of breccia 14321,1404 was able to distinguish between lithic and mineral clasts and the surrounding matrix (Fig. 2). It also provides an idea of the texture within the lithic clasts. Several intriguing clasts were identified within the sample.

Micro-XRF scans on 14305,483 (Figs. 3+4) can easily distinguish different clast lithologies within breccias, estimate bulk compositions, and give textural information, particularly if 3-element composite maps are utilized. Moreover small (~10 μm) mineral grains of geologic importance (e.g., zircon or phosphates) are resolvable even on relatively coarse scans. The micro-XRF scans also yield useful information (albeit fuzzy information) from the bottoms of cm deep depressions.

Discussion: Micro-CT analyses to astromaterials is not a new concept, and has worked well on meteorites in the past [1-3]. The analyses have virtually no impact on the samples, can be done through shielding materials (e.g., Teflon) so the samples can be kept pristine, and provide significant compositional information about the samples that will allow for more efficient distribution and use of samples. Micro-CT and micro-XRF scanning will likely become a standard part of future PET studies of astromaterials. These techniques can also be retroactively applied to existing astromaterial collections to enhance the scientific return of these collections, particularly the Apollo and ANSMET meteorite sample suites. For example, new clasts of important lunar lithologies (e.g., granites, KREEP basalts, etc.) can be identified within Apollo breccias, providing "new" samples that can be used to address a variety of important scientific questions about the origin and evolution of the Moon.

References: [1] Towner M. C. et al. 2010. LPS 41: #1758. [2] McCausland P. J. et al. 2010. LPS 41: #2584. [3] Smith CL et al. (2013) *MAPS,* **76**, Abstract #5323. **Acknowledgements:** A special

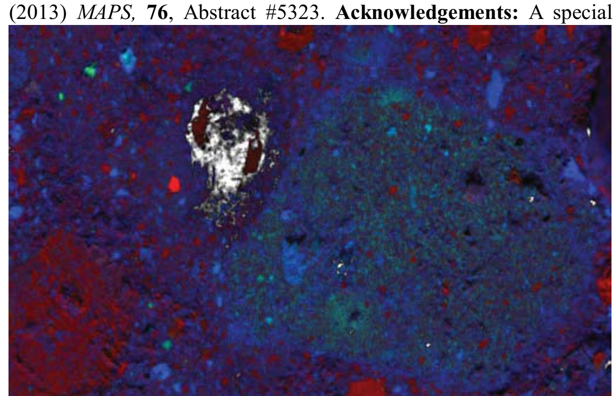

Fig. 4: RGB composite images of micro-XRF derived x-ray maps of 14305,483. Red = Ca, green = Mg, Fe = blue. The K x-ray map is shown in white and superimposed on the map. Field of view is 3 cm.

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